# FIFTEEN YEAR RESULTS OF THREE HARVESTING METHODS ON COMPOSITION AND DEVELOPMENT OF REGENERATION IN SOUTHERN INDIANA UPLAND HARDWOODS

Richard B. Standiford and Burnell C. Fischer[1/]

Abstract.--During 1964-67, 10 stands at the Southern Indiana Purdue Agricultural Center were harvested using three regeneration cutting methods - diameter limit cutting, irregular shelterwood or patch clearcutting. Patch clearcuts were approximately 4 tree heights in size.

Permanent regeneration transects established in each stand prior to cutting were remeasured 1, 3-6, and 12-15 years after cutting. Species were tallied into 4 groupings - oaks, cherry-ash-poplar (CAP's), maples, and miscellaneous (elm, sassafras, black gum, hickory, etc.) and stratified into height classes.

Prior to harvest, 80% of the total volume in these stands was in oak species. Of the approximately 3,500 stems of advance regeneration 20% were oaks, 10% CAP's, 16% maples and 54% miscellaneous species. The number of oaks greater than 5 feet averaged 43 per acre. In 1979 the height of the dominant crown class of the regeneration, representing 800-1000 stems per acre per treatment, was 6-12 feet for diameter limit cutting and 12-20 feet for the irregular shelterwood and patch clearcuts. Over time the percentage of oak decreased, CAP's and maples increased and miscellaneous remained about the same with only small differences between the three cutting methods. Thus cutting method had little effect on reproduction composition. A comparison of regeneration methods showed a significant increase in number of grapevines over the uncut control plots but no differences between cutting methods.

Additional keywords: silviculture, natural regeneration, upland central hardwoods, diameter limit cutting, irregular shelterwood, patch clearcutting.

## INTRODUCTION

Most private nonindustrial woodland owners in the central hardwood region rely on natural regeneration to restock their woodlands. This natural regeneration results from a variety of types of partial cuttings or silvicultural systems. In many cases the species composition of regeneration following timber harvesting is quite different than the species composition of the harvested timber. This change in species composition is usually considered undesirable, particularly in light of the "oak regeneration problem" (Merritt, 1979). Although clearcutting of upland central hardwoods is recommended as the regeneration system which will lead to the highest percentage of desirable tree species

1/ Professional Forester and Assistant Professor of Silviculture, Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907.

(Roach and Gingrich, 1968; Sander, 1977), many private woodland owner's management objectives will not permit clearcutting. This has resulted in foresters and landowners alike searching for alternative silvicultural systems to successfully manage and regenerate upland central hardwoods.

During 1964 to 1967, fifteen stands of upland hardwoods at the Southern Indiana Purdue Agricultural Center (SIPAC) were included in a study investigating the effects of three different regeneration harvesting strategies on the species composition of natural regeneration. The regeneration cutting methods were chosen for their appropriateness for private nonindustrial woodlands. The species composition and stand development for each cutting method has been monitored over the past 12 to 15 year period.

## THE STUDY AREA

The upland hardwood stands included in this area are typical of the unmanaged woodlots in the area. The old growth timber was harvested in 1914, with additional high-grading harvests occurring in 1932 and 1952. The study area has a history of livestock grazing prior to 1953. SIPAC is located on the unglaciated sandstone-shale soils of south-central Indiana. The soils are in the Wellston, Gilpin and Zanesville series, with a black oak site index of 70 to 80.

In 1964 the stands in this study had an average basal area of 42 square feet per acre in trees 10 inches and larger, and averaged 2,190 board feet per acre (Doyle) prior to harvest. The species composition of this volume was 48.9 percent white oak (*Quercus alba* L. and *Quercus muehlenbergii* Michx.), 16.9 percent red oak (*Quercus rubra* L.), 14.4 percent black oak (*Quercus velutina* Lam.), 7.1 percent hickory (*Carya spp.*), 4.7 percent yellow poplar (*Liriodendron tulipifera* L.), and 8.0 percent other (*Fraxinus americana* L., *Acer saccharum* Marsh., *Acer rubrum* L., *Prunus serotina* Ehrh., *Juglans nigra* L., *Platanus occidentallis* L., and *Ulmus rubra* Muhl.).

## METHODS

The three regeneration harvesting methods selected for this study were diameter limit cutting, irregular shelterwood and patch clearcutting. The study was conducted in 15 blocks, averaging 2.8 acres per block. Five of these blocks were control areas (2 established in 1964 and 3 established in 1966), 2 blocks were harvested using individual tree selection (1966, 1967), 3 blocks were harvested by the irregular shelterwood method (1964, 1964, 1966) and 5 blocks were cleared representing patch clearcutting (1964, 1964, 1966, 1966, 1967).

Those blocks receiving the diameter limit cutting treatment were harvested using a 16 inch diameter at breast height (dbh) limit. This method of harvesting approximates what is commonly considered "selective" harvesting in the upland hardwoods. The actual diameter limit specifications varies with local market conditions. Infact, the residual stand structure exhibited the classic inverse J-shaped curve. The diminution quotient (Sammi, 1961) for the residual stand was approximately 1.5 for two inch diameter classes. Crown cover remained near 100 percent.

The second regeneration harvesting treatment was a combination of irregular shelterwood and reserve seed tree methods. On these blocks approximately 16 subdominant trees to the acre representing about 11 square feet of basal area, were left to develop into high quality sawlog trees and to provide a limited amount of shade for the developing understory. All other trees on these shelterwood blocks, 2 inches dbh and greater were either utilized as sawtimber and pulpwood, or deadened. The irregular shelterwood method is a modification of the shelterwood system, where the overwood trees are retained for a longer period of time than normal. Two age classes, the overwood trees and the developing regeneration, are maintained through at least 20 percent of the rotation. In the reserve seed tree method, seed trees are reserved not only to provide seed for regeneration but also to grow satisfactorily until future harvest. Thus, both seeding capacity and the ability to obtain further increments are tree retention criteria (Smith, 1962). The overwood trees in this study were selected for their predicted capacity to grow into high quality sawtimber and thereby generate an intermediate and cash flow while regenerating the next even-aged stand (Weaver, 1966). These residual overwood trees were not selected for or probably adequate in terms of seed production for the reserve seed tree method. However, the relatively low density of overwood trees gives an appearance of a discontinuous upper story (the overwood) of a two storied stand, corresponding more with the seed tree method. For the purposes of this paper we have chosen to call this an irregular shelterwood.

The third regeneration harvesting treatment was patch clearcutting. The patch clearcuts were each two to four acres in size, with an average opening size of about four tree heights. The floor of a four tree height opening would receive about 70 percent of the available direct solar radiation (Fischer, 1979). All trees in these openings 2 inches dbh and greater were sold as sawtimber and pulpwood or deadened.

Prior to harvesting, permanent regeneration transects were randomly located in each treatment block. Each transect was one chain (66 feet) long and 3.3 feet wide (.005 acres). Of the 111 regeneration transects, 29 were located in the control blocks, 11 in the diameter limit cutting blocks, 21 in the irregular shelterwood blocks and 50 within the patch clearcuts. The sampling intensity of the regeneration transects was 1.3%.

Following the regeneration harvest, the treatment blocks were left to develop naturally. The regeneration transects on the six blocks in the 1964 study were remeasured three times following the harvest cutting (1965, 1970, 1979). The seven 1966 study blocks were remeasured twice after logging (1970, 1979). The two blocks in the 1967 harvesting area were also measured twice after logging (1970, 1979). In each case, species, number and size of the regeneration were measured.

The 1979 remeasurement also included a tally of the number of grapevines (*Vitis spp.*) in the main canopy in each regeneration transect. A vine was tallied if it was rooted within the transect and then directly entered the crown of a tree.

## RESULTS

To simplify the analysis of the large number of species present on the regeneration transects, species were recorded in four groupings. The first group was composed of all oak species. The second group contained black cherry, white ash and yellow poplar and is referred to as CAP's (cherry-ash-poplar) (Roach, 1978). The third species grouping contained maples which were primarily sugar maple. Sugar maple is usually considered an undesirable species for timber production in southern Indiana. The miscellaneous group contained mainly lower-valued species such as elm, sassafras, black gum and hickory.

The amount and type of advance regeneration present in the control and three treatments prior to harvesting are compared in Table 1. There were significantly greater numbers of advance oak regeneration in those blocks which received the diameter limit harvest, whereas the amount of oak regeneration in the other treatment blocks was fairly constant. This resulted because one of the two individual tree selection blocks containing 7 of the 11 transects for this treatment, was the only block in this study with a south aspect. The number of trees in the CAP's and maple groups were about the same for all four treatments. There was a significantly larger number of total trees in the diameter limit cutting area because of the large amount of oak advanced regeneration. With the exception of the diameter limit cutting blocks, the stands were fairly uniform in the preharvest species composition of the advance regeneration.

Table 2 shows the number of trees per acre in the irregular shelterwood and patch clearcut blocks one year after harvesting. First year regeneration data were not collected for the diameter limit cut blocks. A comparison of the two treatments showed a significantly greater number of oak reproduction in the patch clearcut treatment. An apparent difference between these two treatments is in the larger number of 0 to 1 foot trees in the CAP's group in the patch clearcuts than in the shelterwood; however, these numbers are not statistically significant because of the large amount of within treatment variability. The number of trees per acre in the maple group is similar for both harvesting types. Both treatments had a large increase in the number of 0 to 1 foot trees in the miscellaneous category one year after harvesting. There was a significantly greater number of trees per acre in the 1 to 5 foot miscellaneous category for the patch clearcuts. Almost 2,000 more total trees per acre are found in the patch clearcuts. The decrease in the number of trees greater than 5 feet in height following both types of harvesting is probably the result of logging damage to these larger trees.

The number of trees per acre for the three treatments, 3 to 6 years after harvesting is shown in Table 3. Because of the variation in time in treatment initiation and data collection, data were grouped into 3-6 years (Table 3) and 12-15 years (Table 4) for statistical comparisons. Such groupings could lead to invalid conclusions, particularly in the 3-6 year comparisons. However, the wide height class limits should compensate for the multi-year comparisons.

The effect of the larger number of oaks in the diameter limit cut areas prior to harvesting (Table 2) was not as pronounced 3-6 years after treatment, although the number of 0 to 1 foot and total trees in the oak group was signif-

Table 1.--Number of trees per acre by species group and height class for the control and 3 treatments prior to harvesting. The number of trees for each treatment by species group and height class are compared using Duncan's New Multiple Range Test (Steel and Torrie, 1960). Different superscripts indicate a significant difference between treatments at the 0.05 level.

| SPECIES GROUP | HEIGHT CLASS (ft) | TREATMENTS | | | |
|---|---|---|---|---|---|
| | | Control | Diameter Limit Cut | Irregular Shelterwood | Patch Clearcut |
| OAKS | 0-1 | $517^{a}$ | $1636^{b}$ | $419^{a}$ | $616^{a}$ |
| | 1-5 | $131^{c}$ | $345^{d}$ | $95^{c}$ | $152^{c}$ |
| | >5 | $21^{e}$ | $182^{f}$ | $19^{e}$ | $28^{e}$ |
| | Total | $669^{g}$ | $2163^{h}$ | $533^{g}$ | $796^{g}$ |
| CAP's | 0-1 | 214 | 255 | 248 | 308 |
| | 1-5 | 76 | 145 | 57 | 48 |
| | >5 | 34 | 18 | 19 | 28 |
| | Total | 324 | 418 | 324 | 384 |
| MAPLE | 0-1 | $117^{h,i}$ | $236^{h}$ | $38^{i}$ | $132^{h,i}$ |
| | 1-5 | 103 | 218 | 95 | 164 |
| | >5 | 214 | 164 | 381 | 336 |
| | Total | 434 | 618 | 514 | 632 |
| MISC. | 0-1 | 952 | 1182 | 914 | 848 |
| | 1-5 | $1007^{j}$ | $945^{j,k}$ | $733^{j,k}$ | $580^{k}$ |
| | >5 | 214 | 327 | 324 | 192 |
| | Total | 2173 | 2454 | 1971 | 1620 |
| TOTAL | 0-1 | $1800^{l}$ | $3309^{m}$ | $1619^{l}$ | $1904^{l}$ |
| | 1-5 | $1317^{n,o}$ | $1653^{n}$ | $980^{o}$ | $944^{o}$ |
| | >5 | 483 | 691 | 743 | 584 |
| | Total | $3600^{p}$ | $5653^{q}$ | $3342^{p}$ | $3432^{p}$ |

Table 2.--Number of trees per acre by species group and height class for two treatments one year after harvesting. Significant differences (*) between treatments were determined using Student's - t Test (Steel and Torrie, 1960). Average preharvest trees per acre for control, shelterwood, and patch clearcut areas is shown for comparison.

| SPECIES GROUP | HEIGHT CLASS (ft) | TREATMENTS | | PRE-HARVEST TREES/AC. |
|---|---|---|---|---|
| | | Irregular Shelterwood | Patch Clearcut | |
| OAKS | 0-1 | 147 | 340 | 546 |
| | 1-5 | 67 | 230 | 134 |
| | >5 | 27 | 20 | 24 |
| | Total | 241 | 590* | 704 |
| CAP's | 0-1 | 387 | 1130 | 268 |
| | 1-5 | 253 | 190 | 58 |
| | >5 | 0 | 0 | 28 |
| | Total | 640 | 1320 | 354 |
| MAPLE | 0-1 | 227 | 170 | 108 |
| | 1-5 | 147 | 230 | 132 |
| | >5 | 160 | 160 | 310 |
| | Total | 534 | 560 | 550 |
| MISC. | 0-1 | 1573 | 1590 | 892 |
| | 1-5 | 387 | 1230* | 736 |
| | >5 | 93 | 130 | 226 |
| | Total | 2053 | 2950 | 1854 |
| TOTAL | 0-1 | 2334 | 3230 | 1814 |
| | 1-5 | 854 | 1880* | 1060 |
| | >5 | 280 | 310 | 588 |
| | Total | 3468 | 5420* | 3462 |

Table 3.--Number of trees per acre by species group and height class for 3 treatments, 3 to 6 years after harvesting. The number of trees for each treatment by species group and height class are compared using Duncan's New Multiple Range Test (Steel and Torrie, 1960). Different superscripts indicate a significant difference between treatments at the 0.05 level.

| SPECIES GROUP | HEIGHT CLASS (ft) | TREATMENTS | | |
|---|---|---|---|---|
| | | Diameter Limit Cut | Irregular Shelterwood | Patch Clearcut |
| OAKS | 0-1 | 382[a] | 118[b] | 129[b] |
| | 1-5 | 582 | 245 | 370 |
| | >5 | 218 | 109 | 163 |
| | Total | 1182[c] | 472[d] | 662[d] |
| CAPS | 0-1 | 236[e] | 91[e,f] | 79[f] |
| | 1-5 | 382 | 691 | 875 |
| | >5 | 36[g] | 355[g,h] | 388 |
| | Total | 654 | 1137 | 1342 |
| MAPLE | 0-1 | 91 | 18 | 21 |
| | 1-5 | 309 | 336 | 225 |
| | >5 | 236 | 509 | 242 |
| | Total | 636[i] | 863[i] | 488[j] |
| MISC. | 0-1 | 327 | 300 | 117 |
| | 1-5 | 1436 | 1418 | 1529 |
| | >5 | 636 | 973 | 1154 |
| | Total | 2399 | 2691 | 2800 |
| TOTAL | 0-1 | 1036[k] | 527[l] | 346[l] |
| | 1-5 | 2709 | 2690 | 2999 |
| | >5 | 1126 | 1946 | 1947 |
| | Total | 4871 | 5163 | 5292 |

icantly greater than the shelterwood and patch clearcut treatments (Table 3). There were significantly more CAP's greater than 5 feet in the patch clearcuts than the diameter limit areas. While there were greater number of CAP's in the patch clearcuts one year after harvest (Table 1) by the third to sixth year there was almost no difference in the number of CAP's per acre between the shelterwood and patch clearcut treatments. There were significantly fewer total maples in the patch clearcuts than in the other two harvesting treatments. The increased number of miscellaneous species in the patch clearcuts one year after harvesting (Table 2) disappeared 3 to 6 years after harvesting. No statistical difference in the total number of trees per acre were found between the three treatments, although there were more total small trees (0 to 1 foot height class) and less total tall trees (greater than 5 foot height class) in the diameter limit cut areas than the other two harvesting areas.

Table 4 gives the number of trees per acre for the three treatments 12 to 15 years after harvest. Because of the height growth which has occurred, the number of trees per acre are reported for six height classes. The diameter limit cutting block with the south aspect is not included in this table because it was lost to highway construction. Because only 4 transects remained in the diameter limit cut treatment this treatment was not included in statistical tests for 1979 data, but is presented for comparison. Few statistical differences were found in species composition of the regeneration between the irregular shelterwood and patch clearcutting treatments.

The 1979 grapevine survey in the regeneration transects for the control and three harvesting treatments found a significant increase ($p = 0.05$) in the number of grapevines in both the irregular shelterwood and patch clearcutting treatments. The survey found 74 vines per acre in the control area, 200 per acre in the diameter limit cutting blocks, 273 per acre in the irregular shelterwood blocks and 236 per acre in the patch clearcuts. These 3 to 4-fold increases in vines resulted from no preharvest treatment of grapevines.

## DISCUSSION AND CONCLUSIONS

Prior to harvest, 80.2% of the total volume in these stands was in oak species. Approximately 3,500 stems of advance regeneration per acre were present. The species composition of this advance regeneration was 20.3% oak species, 10.2% CAP's, 15.9 maples, and 53.6% miscellaneous species.

### Stand Development

One year after harvest, the patch clearcuts had a higher number of total oaks, CAP's, miscellaneous species and total trees than the irregular shelterwood areas. Both types of timber harvesting increased the number of CAP's and miscellaneous species over the preharvest condition.

Three to six years after harvesting, there were a larger number of oaks in the diameter limit cutting areas than in the other two harvesting treatments. However, this reflected the larger number of advance oaks in the diameter limit plots prior to harvest, and was not a result of the method of timber harvesting. The species composition differences between shelterwood and patch clearcuts was not as pronounced after 3 to 6 years of stand development. The number of CAP's and miscellaneous species were approximately equal for these two cutting methods

Table 4.--Number of trees per acre by species group and height class for 3 treatments, 12-15 years after harvesting. Significant differences (*) between irregular shelterwood and patch clearcut treatments were determined using Student's - t test (Steel and Torrie, 1960). The diameter limit cut treatment was not included in t-test because of destruction of most regeneration transects.

| SPECIES GROUP | HEIGHT CLASS (ft) | TREATMENTS | | |
|---|---|---|---|---|
| | | Diameter Limit Cut | Irregular Shelterwood | Patch Clearcut |
| OAK | 0-2 | 300 | 355 | 272 |
| | 2-6 | 0 | 64* | 16 |
| | 6-12 | 50 | 18 | 44 |
| | 12-20 | 0 | 18 | 44 |
| | 20-30 | 0 | 9 | 20 |
| | >30 | 0 | 0 | 0 |
| | Total | 350 | 464 | 396 |
| CAP's | 0-2 | 350 | 455 | 232 |
| | 2-6 | 300 | 109 | 96 |
| | 6-12 | 50 | 127 | 60 |
| | 12-20 | 50 | 82 | 68 |
| | 20-30 | 0 | 64 | 48 |
| | >30 | 0 | 9 | 16 |
| | Total | 750 | 846 | 520 |
| MAPLE | 0-2 | 300 | 836 | 288 |
| | 2-6 | 300 | 236 | 224 |
| | 6-12 | 200 | 236 | 192 |
| | 12-20 | 50 | 200 | 136 |
| | 20-30 | 50 | 109* | 12 |
| | >30 | 0 | 0 | 16 |
| | Total | 900 | 1617 | 868 |
| MISC. | 0-2 | 2450 | 2018 | 2080 |
| | 2-6 | 600 | 518 | 492 |
| | 6-12 | 400 | 364 | 516 |
| | 12-20 | 100 | 264 | 400 |
| | 20-30 | 0 | 82 | 76 |
| | >30 | 50 | 18 | 12 |
| | Total | 3600 | 3264 | 3576 |
| TOTAL | 0-2 | 3400 | 3664 | 2872 |
| | 2-6 | 1200 | 927 | 828 |
| | 6-12 | 700 | 745 | 812 |
| | 12-20 | 200 | 564 | 648 |
| | 20-30 | 50 | 264 | 156 |
| | >30 | 50 | 27 | 44 |
| | Total | 5600 | 6191 | 5360 |

in the third to sixth year following harvesting. The main differences between the diameter limit treatment and the other two treatments was that in the diameter limit treatments only about one half as many CAP's were present and the height of the regeneration layer was considerably shorter.

Twelve to fifteen years after timber harvesting, the regeneration results from patch clearcuts and irregular shelterwood harvesting were very similar. However, there were fewer maple stems in the patch clearcuts. The similarity between these two cutting methods may be explained by the low residual stocking of the overwood trees in the irregular shelterwood. The 16 residual trees per acre, with an average dbh of 11.1 inches, represented 9 percent stocking (Gingrich, 1967). At this stocking percent, the stand was quite open, initially receiving about 90 percent of full light (Sander, 1979). In terms of regeneration layer light levels, this was comparable to light levels in the patch clearcuts.

The species composition of the trees in the dominant/codominant crown class of the regeneration layer best demonstrates the effect of these three treatments. About 800 to 1,000 trees per acre in all treatments have expressed dominance in the subsequent twelve to fifteen years after harvest, and form the main canopy of the next stand. The height of the dominant/codominant crown class for the diameter limit cutting area is 6 to 12 feet. The approximately 1,000 stems/acre in this size class are composed of 5% oaks, 10% CAP's, 30% maple and 55% miscellaneous. The more open conditions of the irregular shelterwood and patch clearcuts has resulted in a taller dominant/codominant crown which is 12 to 20 feet containing about 850 trees per acre. The irregular shelterwood regeneration is 3.2% oaks, 18.1% CAP's, 36.1% maple and 42.6% miscellaneous while the patch clearcuts regeneration is 7.5% oaks, 15.6% CAP's, 19.3% maple and 57.6% miscellaneous. The initial poor species composition of the advance regeneration appears to have contributed to the development of a regeneration layer still deficient in high value species 12 to 15 years after harvesting for both the irregular shelterwood and patch clearcuts. The conclusion can be made that the cutting treatments have had no real effect on the composition of the reproduction.

## Oak Regeneration

The patch clearcuts have the largest percentage of total oaks in the dominant/codominant crown classes, although the percentage of oaks was low for all three regeneration harvest methods. Several studies indicate that in order for oak to be successfully regenerated in harvested stands, it must be present in sufficient numbers as advance regeneration at least 4.5 feet in height (Sander and Clark, 1971; Sander 1972; Sander et al, 1976) or develop from stump sprouts (Johnson, 1977). Although there was an average of 704 stems per acre of oak advance growth prior to harvest for the control, shelterwood and patch clearcut treatments, only 24 of these stems were greater than 5 feet tall (Table 2). These 24 trees would be the only advance regeneration with a capacity to compete successfully and occupy a position of dominance in the future stand.

To further illustrate the low potential for oak regeneration in the study areas, only 8 of the 71 regeneration transects in the patch clearcut and shelterwood areas contained at least one stem of oak advance regeneration greater than 5 feet tall prior to harvest. Of the 63 transects without suitable advance

growth, only 10 (16%) had at least one oak in the dominant/codominant crown class twelve to fifteen years after harvest. In the 8 transects that did have suitable oak advance reproduction prior to harvest, only 2 (25%) had at least one oak in the main canopy of the regeneration layer twelve to fifteen years after harvest.

It may be possible to keep a sizeable percentage of oaks in the main canopy throughout a rotation if the 30 to 60 oak trees per acre currently in the main canopy are well distributed and receive a crop tree release to keep them in a dominant position. However, the timing of this treatment and its relative success has not been completely demonstrated (Trimble, 1974; Smith, 1979). Oliver (1978) suggests that a crop tree release is not even necessary because these sapling oaks will eventually become dominants.

## Grapevines

Grapevines represent a serious problem in many central hardwood forest stands. Top breakage and even girdling may result in areas with high concentrations of grapevines. This study demonstrated the significant impact of timber harvesting on increasing the number of "problem" grapevines per acre and was consistent with trends suggested in other studies (Smith, 1979). The cutting of grapevines several years before harvesting, as suggested by Smith (1979), should reduce the numbers of grapevines in the post harvest situation. Whether additional grapevine treatments would be needed after stand establishment is unknown.

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